

# Experimental Investigation of modal parameters of pre and post impact damaged composite laminates

Sachin K. Patil<sup>1</sup>, Avinash Kumar K M<sup>1</sup>, Ramesh S Sharma<sup>2</sup>

<sup>1</sup>Post Graduate Students, <sup>2</sup>Professor

Department of Mechanical Engineering, RV College of Engineering, Bengaluru

## ABSTRACT

Composite materials are preferred over the traditional engineering materials due to their low density, high strength to weight ratio, have high flexural rigidity, fatigue resistance and excellent damping properties. Damping properties of laminated composites depend on the fiber orientation, stacking sequence, volume fraction etc. Every composite component is subjected to a host of different variety of loads, inducing a wide range of vibrations under different boundary conditions. The damping properties are affected in such conditions. In this paper, the modal properties of a bidirectional GFRP plate having unit aspect ratio are estimated using experimental modal analysis for F-F-F-F and C-F-F-F boundary conditions for pre and post impact damage scenarios. The damping ratio of the specimen for F-F-F-F boundary condition increases after induction of damage. For C-F-F-F boundary condition, however, damping ratio decreases as the mode number increases, reaches a minimum value for fifth mode and increases for higher modes. This particular damping behaviour of the material is very difficult to interpret and the mechanics involved in affecting the damping properties have to be revisited.

**Keywords:** GFRP, Damping, Impact Damage, Laminate, Modal parameters

## INTRODUCTION

The advent of composite materials into our everyday lives is unassailable. Application of composites in aerospace industry is ever increasing with more and more compatible combinations of composite materials being produced every day. The basic type of composite material used is a laminated composite, containing layers of fiber, equally spaced in a matrix, bonded by an adhesive. It is analytically and experimentally verified that the damping capability of a composite material mainly depends on the specimen thickness, fiber content, its diameter and orientation, stacking sequence, loads it is subjected to, surface treatment of the reinforcement, and even on damage induced on it during its usage. These parameters on which the damping properties depend do not exhibit a definite trend, are interdependent and they vary ficklely goading the researchers to delve deep to formulate new theories and models

to factor in all possible variables. Composite materials, in their service time are subjected to a wide spectrum of loads, stresses, strains stemming out from different operating and boundary conditions. For example, an airplane which is increasingly being made of composite material, during its flight may be hit by a bird or hailstones; tools may be dropped during assembly of an automobile, the hull of a ship may be hit by an iceberg. Various types of stresses and the possible damages the composites endure are fiber-matrix debonding, fiber misalignment, fiber breakage, delamination, matrix cracks, impact damage, inclusions, voids et al and accordingly the damping properties vary. Hence studying the damping properties of a pre and post damaged composites are of immediate interest.

A Trevioso et al. [1] reviewed chronologically the test methods available

for damping estimation in order to describe the timeline of the development of the theoretical knowledge in this field. R. Chandra [2] et al carried out a detailed review on damping studies in fiber reinforced composites and concluded that the experimental modal analysis technique was an effective method to evaluate damping properties of composites. J Alexander et al [3] studied the damping characteristics of GFRP laminates and concluded that the frequency changes for different boundary conditions was high for fixed-fixed conditions. J Alexander et al [4] conducted modal analysis for carbon reinforced epoxy resin and basalt resin composites at various boundary conditions and concluded that the fixed edge boundary condition provided better damping than other boundary conditions. Zeki Kiral et al. [5] investigated the effect of impact failure of the damping characteristics of beam-like composites, damaged with different impact energies at different points from the clamped location. The study concluded that damping changes decrease as impact location moves away from clamped edge. Ricardo de Medeiros et al. [6] carried out experimental analysis for vibration based damage detection in composite plates and concluded that although there may be difficulties in obtaining the location damage, modal analysis provides local as well as global information on structural health monitoring. M. A Perez et al. [7] conducted a low velocity impact test on a carbon fiber reinforced composite and an ultrasonic C-scan was conducted to evaluate the damage and to conclude that vibration testing was an effective method to characterize the location and vicinity of the damage. Ronald F. Gibson [8] conducted modal analysis on four different specimens of composite plate before and after crash induced de-bonding damage. The results showed that the frequencies decreased at each mode. Specific Damping Capacity (SDC), which quantified

damping, was observed to show an increasing trend for the damaged specimens. Cynthia A Bourne [9] investigated the significance of material damping as a means of quantifying fatigue damage in composites. The conclusions drawn were that the structural damping decreased with damage and the frequency tended to decrease due to damage. Ramesh S Sharma [10] et.al investigated the modal parameters of composite sandwich panels with rigid inserts. Experimental observations showed that the composite specimen with rigid inserts most noticeably improved modal parameters. The literature review provided insight about the significance of modal analysis, in particular, damping factor as a measure of damping. No literature encountered in our survey has reviewed the damping properties of a low velocity impact damaged GFRP for both C-F-F-F and F-F-F-F boundary conditions. As such, this current study aims to address the change in damping properties of a GFRP specimen due at low velocity impact damage for two different boundary conditions.

## METHODOLOGY

Modal testing is carried out by subjecting the undamaged specimen to a known excitation and modal parameters are obtained for F-F-F-F and C-F-F-F boundary conditions. The specimen is subjected to impact loading using a low velocity impact testing machine. Modal testing is carried out on the damaged specimen for a known excitation and modal parameters are obtained for F-F-F-F and C-F-F-F boundary conditions

## EXPERIMENTATION:

### Modal Analysis of undamaged specimen

The experimental specimen is glass/epoxy bi-woven composite laminate. The dimensions of the plate are 170 mmx150 mmx4 mm. A 20 mm strip on the 170 mm side was drilled with 4 holes of 8 mm each so as to clamp the specimen. The

composite specimen was clamped using four 8mm bolts and then tightened by a torque wrench with a torque of 9 N-m to obtain Clamped-Free-Free-Free (C-F-F-F) boundary condition and suspended using an elastic cord to simulate Free-Free-Free-Free (F-F-F-F) boundary condition as shown in figures 3.1 and 3.2 respectively. The uniform torque applied ensures that there is minimal deviation from the experimental results due to bolting. The specimen was divided into 36 equally spaced grid points and accelerometer is mounted at the 36<sup>th</sup> grid point. Specimen was triggered through the impact hammer by a tap and the response was recorded by the accelerometer which converts the voltage into natural frequency and mode shapes through the FFT analyzer. At each point, the specimen was triggered 4 times and average of these four results was recorded.



**Fig 1.1:** *Clamped (C-F-F-F) Boundary Condition*



**Fig 1.2:** *Free-Free (F-F-F-F) Boundary Condition*

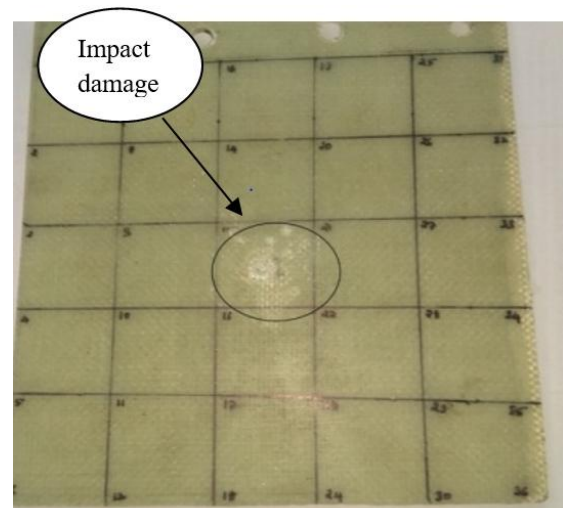
### **Low Velocity Impact damage on specimen**

Damage was induced in the specimen by low velocity impact testing machine as shown in figure 3.3. A hemispherical indenter was used weighing 3.6 kg and the indenter was dropped from a height of 0.85 m resulting in impact energy of 30 J.

The damage induced was clearly visible on naked eye inspection as shown in figure 3.4. The visibly damaged specimens were once again subjected to modal analysis tests and results obtained were recorded.



**Fig 1.3:** *Low velocity test set up and the damaged specimen*



**Fig 1.4:** *Damaged specimen*

## RESULTS AND DISCUSSION

The modal parameters were extracted from the modal test carried out for two different boundary conditions. The first five modes were considered for analysis owing to limitation of the number of grid points chosen. The natural frequency decreased for each mode in C-F-F-F boundary condition post damage. In F-F-F-F condition, the natural frequency substantially increased for the fundamental mode but reduction at higher modes is seen; on the other hand natural frequency decreased post damage for C-F-F-F boundary condition.

**Table 1.1:** Frequencies Comparison for damaged and undamaged specimen

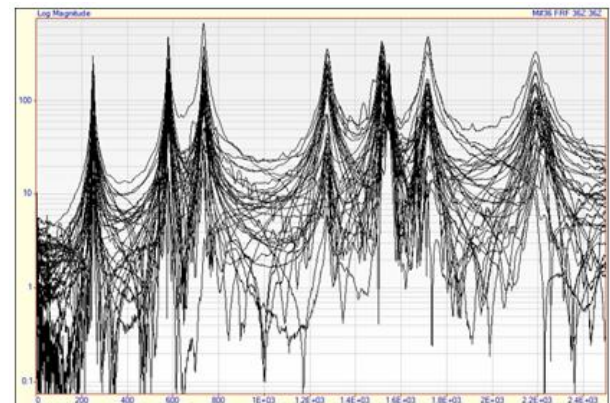
(F-F-F-F) Boundary Condition			
Mode No.	Undamaged (Hz)	Damaged (Hz)	%Change
1	251	256	1.99
2	580	590	1.72
3	737	741	0.54
4	1280	1280	0.00
5	1520	1510	-0.66

**Table 1.2:** Frequencies Comparison for damaged and undamaged specimen

(C-F-F-F) Boundary Condition			
Mode No.	Undamaged (Hz)	Damaged (Hz)	%Change
1	84.1	82.8	-1.55
2	165	163	-1.21
3	529	496	-6.24
4	589	582	-1.19
5	654	634	-3.06

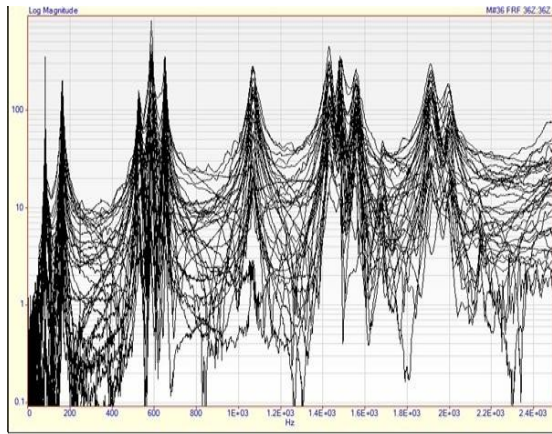
Table 1.1 shows the experimental values of natural frequency obtained for the undamaged and damaged specimens for

the F-F-F-F boundary condition. The percentage of increase in natural frequency for the fundamental mode for F-F-F-F condition is marginally higher (1.99%) but significantly decreases for higher mode (0.66%). Similarly, table 4.2 depicts the natural frequency values obtained for the undamaged and damaged specimens under C-F-F-F condition. The percentage deviation in fundamental frequency for C-F-F-F condition is 1.55% whereas in higher modes the difference in natural frequency is high. At 4<sup>th</sup> mode the difference noticed between undamaged and damaged specimens is 3.06%. This is due to the influence of stiffness parameter in undamaged specimens at higher modes for C-F-F-F condition. The data recorded for each boundary condition is exported to ME Scope software tool for further analysis. The natural frequencies and the damping ratio are obtained from the frequency response function graphs as indicated in figures 2.1 and 2.2.



**Fig 2.1:** Typical FRF Plot for F-F-F-F Condition

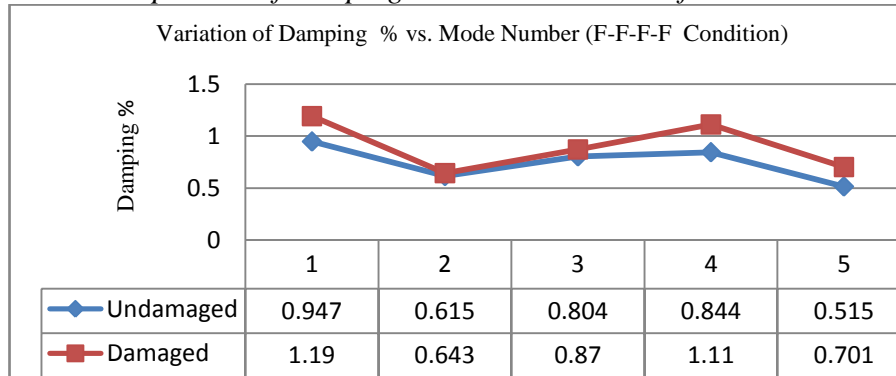




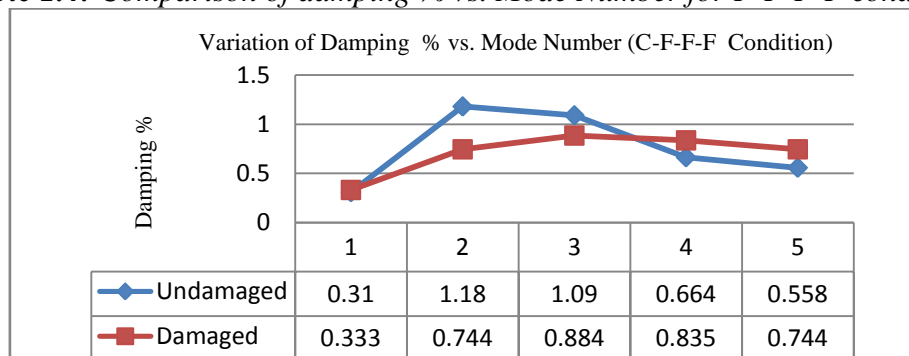
**Fig 2.2:** Typical FRF plot obtained for C-F-F-F condition

The damping factor has increased at each mode in F-F-F-F condition. In C-F-F-F condition there is an improvement in damping factor observed at higher modes. This can be attributed to the dissipation of energy due to possible delaminating and matrix crack. Table 1.4 provides the values of percentage damping for the first five modes in case on F-F-F-F boundary condition while Table 4.4 provides the damping percentage for the first five modes in case of C-F-F-F boundary condition.

**Table 1.3:** Comparison of damping % vs. Mode Number for C-F-F-F condition



**Table 1.4:** Comparison of damping % vs. Mode Number for F-F-F-F condition



## CONCLUSIONS

The modal analysis was performed for GFRP laminates for F-F-F-F and C-F-F-F conditions before and after inducing damage. Based on the modal parameters reported, it is noticed that in post-damage, the frequency value decreases for C-F-F-F condition and similar trend is observed for

higher modes in F-F-F-F condition. The damping factor increased post-damage for F-F-F-F condition at every mode and at higher modes for C-F-F-F condition. Results indicate the influence of modal parameters on pre and post impacted composite laminates that have significant role to play in the design of composite

structures subjected to dynamic loading conditions.

### Acknowledgments

Authors would like thankfully acknowledge the Management, Principal and Head of the Department of Mechanical Engineering in extending their support and encouragement in the execution of this project work.

### REFERENCES

1. Treviso, B. Van Genechten, D. Mundo, M. Tournour, "*Damping in composite materials: Properties and models*", Composites Part B (78), 2015, pg. 144-152
2. R. Chandra, S.P. Singh, and K. Gupta. Damping studies in fiber-reinforced composites-a review. Composite Structure, vol.46, pp41–51, 1999.
3. J. Alexander, B.S.M. Augustine, "*Free Vibration and Damping characteristics of GFRP and BFRP Laminated Composites at Various Boundary Conditions*", Indian Journal of Science and Technology, Vol. 8(12), DOI: 10.17485/ijst/2015v8i12/54208, June 2015
4. J. Alexander, HastonAmit Kumar, Dr.Bsm Augustine, "*Frequency Response of Composite Laminates at Various Boundary Conditions*", International Journal of Engineering Science Invention, ISSN(print): 2319-6726, pg. 11-15
5. ZekiKıral, Bülent Murat İçten, BinnurGörenKıral, "*Effect of impact on damping characteristics of beam-like composite structures*", Composites Part B (43), 2012, pg. 3053-3060
6. Ricardo de Medeiros, MuriloSartorato, FlavioDonizeti Marques, VolneiTita, Dirk Vandepitte, "*Vibration - based Damage identification applied for composite plate: Experimental analyses*", 22<sup>nd</sup> International Congress of Mechanical Engineering (COBEM 2013), ISSN: 2176-5480
7. Marco A Perez, Lluís Gil, SegioOller, "*Impact damage identification in composite laminates using vibration testing*", Composite Structures 108 (2014), pg. 267-276
8. Ronald F Gibson, "*Modal vibration response measurements for characterization of composite materials and structures*", Composites Science and Technology 60 (2000), pg. 2769-2780
9. Cynthia A Bourne, "*Material Damping as a means quantifying fatigue in composites*", Thesis presented to Air force Institute of Technology, Air University (ATC), 1978
10. Ramesh S Sharma, V P Raghupathy, "*Experimental Modal Analysis of Sandwich Panels with Rigid inserts*" International Journal of Material Science, Vol.2, No.3, 2007,pp. 275–281